



Advanced Noise Control Fan Test Rig and Trade Study Summary

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Objective: Determined drive mechanism and site location.
Investigate design concept options and “narrow” alternatives.

- (I) **Background**
(rationale / current facilities / current fans)
- (I) **Summary of Preliminary Feasibility Study**
(drive concepts / facility requirements)
- (II) **Recommendation**





Background

(rationale / current facilities / current fans)



Rationale

BACKGROUND:

- Since 1995 the Advanced Noise Control Fan (ANCF) has significantly contributed to the advancement of the understanding of the physics of fan ***tonal*** noise generation.
- The 9'x15' WT has successfully tested multiple high speed fan designs over the last several decades.
- This advanced several tone noise reduction concepts to higher TRL and the validation of fan tone noise prediction codes



Rationale

CONCERN:

- Low Speed/ Loading/ Pressure nature of ANCF not representative of 9x15 WT / full scale models in the physics of fan ***broadband*** noise generation.
- As a result of ever-quieter fan designs below the background noise levels of 9x15 WT.
- High cost of running of 9x15 WT limits testing to single point designs preventing the parametric investigations required for detailed understanding of the physics necessary for successful technology development.

Rationale



NEED:

A new Fan Test Rig to bridge from TRL 3 to 5 enabling the successful completion of NASA/Industry noise reduction program goals.







Current GRC Facilities

Capabilities of current GRC Fan Noise Test Facilities

- ANCF @ AAPL (TRL 2-3) :
 - Low speed / ultra-low pressure rise / unique acoustic measurements
/ limited aero measurements / high flexibility / parametric studies
/ low cost
- UHB @ 9x15 LSWT (TRL 4-5):
 - High speed / pressure rise / aero & performance measurements /
acoustic measurements w caveats / forward flight effects / point
design / high cost
- W8 (TRL 4):
 - High speed / pressure rise / aero & performance measurements /
moderate costs

NASA Glenn Propulsion Simulators and Facilities Available for Turbofan and Propeller Scale-Model Testing

Operating Limits	Single Rotation Propeller (SRP) Drive Rig	Open Rotor Propulsion Rig (ORPR)	Ultra High Bypass (UHB) Drive Rig	Advanced Noise Control Facility (ANCF)	9'x15' Low Speed Wind Tunnel	8'x6' Supersonic Wind Tunnel	WB Compressor Facility
					<ul style="list-style-type: none"> - Freestream velocity up to Mach 0.22 - Anechoic to 250 Hz 	<ul style="list-style-type: none"> - Freestream velocity from Mach 0.36 to 2.0 	<ul style="list-style-type: none"> - Up to 22" diameter rotors - Core flow simulation capable - Bi-directional rotation
Turbine/Motor Power (SHP)	950	750/rotor	5,015	150 (electric)	N/A	N/A	7,000 (electric)
Shaft RPM	12,200	10,000/rotor	16,850	2,600	N/A	N/A	21,240
Turbine Inlet/Plenum Pressure (psia)	400	315	270	N/A	450	450	Up to 10 psig
Turbine Inlet/Plenum Temperature (deg F)	200	160 min 250 max	500	N/A	700	700	N/A
Turbine Inlet/Plenum Flow (lbm/sec)	15	33	33	N/A	33	35	100
Rotating Balance Forces, thrust (lbs)/torque (ft-lbs)	800/600	400/500 per rotor	4,000/1,530	N/A	N/A	N/A	~1,750
Static Balance Forces, thrust (lbs)/torque (ft-lbs)	N/A	N/A	2,000/1,530	N/A	N/A	N/A	N/A
Comments	<ul style="list-style-type: none"> - Himmelstein transformer for relaying rotating signals 	<ul style="list-style-type: none"> - Counter rotation - Data telemetry units fwd and aft - 12 strain gages available per rotor - Independently controllable rotor speed 	<ul style="list-style-type: none"> - 150 channel slipring for relaying rotating signals 	<ul style="list-style-type: none"> - 4' diameter fan - Very low FPR - Rotor alone capability - Early concept development facility 	<ul style="list-style-type: none"> - -30 to +45 deg AOA capability - Accepts SRP, CRP and UHB drive rigs 	<ul style="list-style-type: none"> - +22 deg AOA capability - Accepts SRP and CRP drive rigs 	<ul style="list-style-type: none"> - Single rotation compressor facility - Rotor alone capability - 100 channel slipring for rotating signals



Summary of Preliminary Feasibility Study

(drive concepts / facility requirements)
only best candidates presented

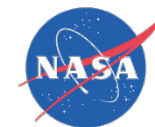


Concept Study Assumptions

What would it look like?

(High level design requirements)

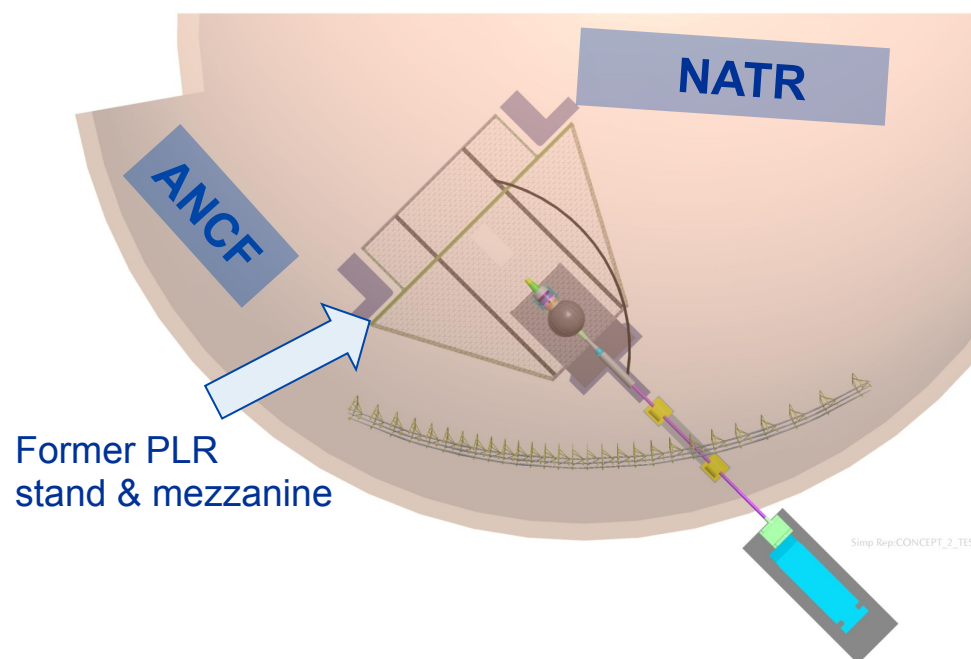
- All electric drive to minimize external support (\$) (consider alternatives)
 - Minimize component noise level (initial metric > 20? dB below WT)
- Tested designs transferable to 9x15 WT - 22" fan diameter*
 - (suggested actual hardware a plus)
- Maintain current measurement capabilities.
 - Far field, in-duct, wall pressures, flow diagnostics, aero-performance
- Sited in AAPL - Minimal impact on existing rigs
 - Ambient temperature conditions
- Static - no external flow lines to complicate / no forward flight effects



ANCF II Location in AAPL

This plan view shows the proposed location of the new test rig with respect to current facility layout.

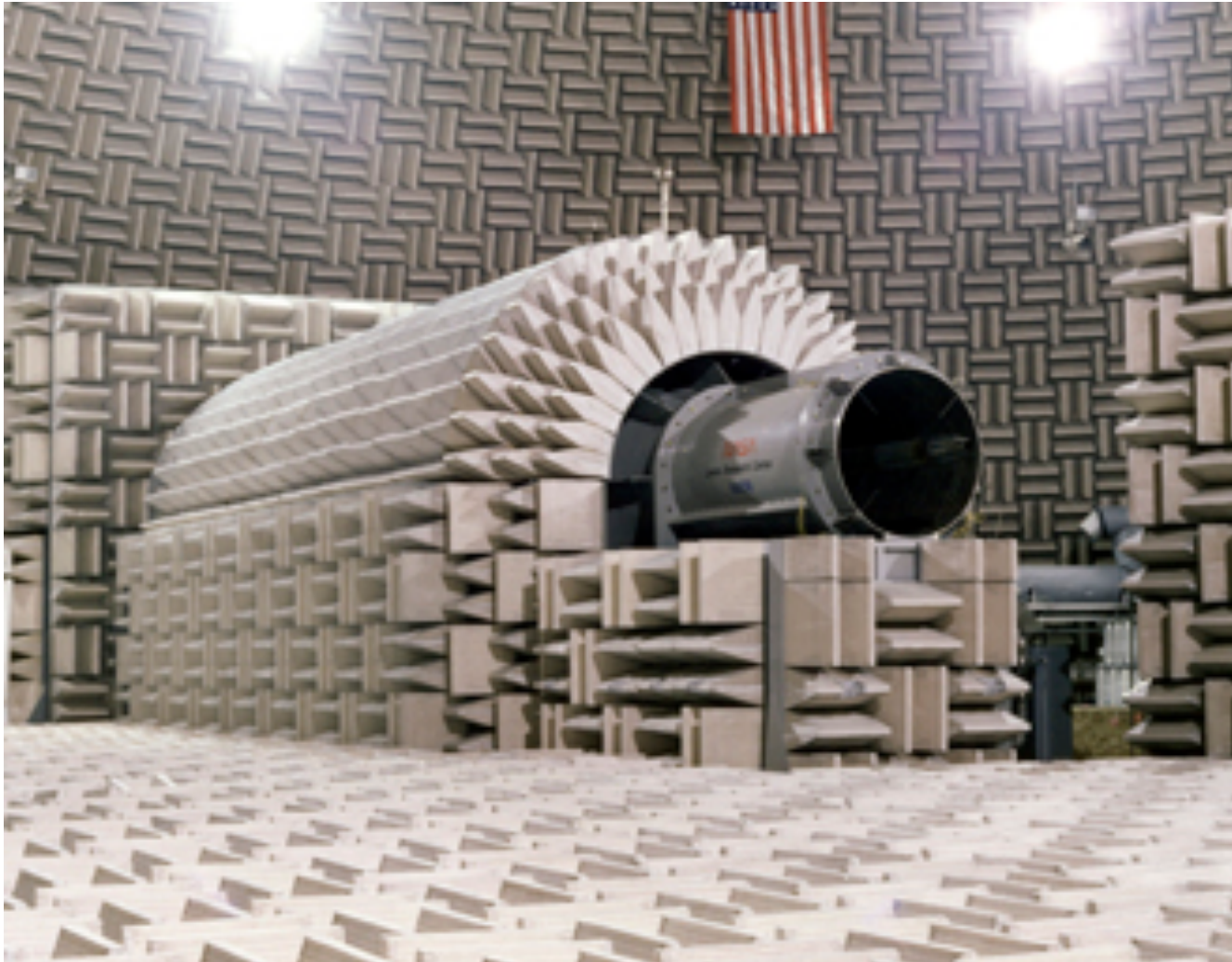
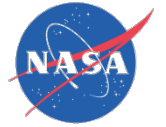
ANCF II test rig would use current thrust stand area in the AAPL with the mezzanine used as a work platform for research hardware access

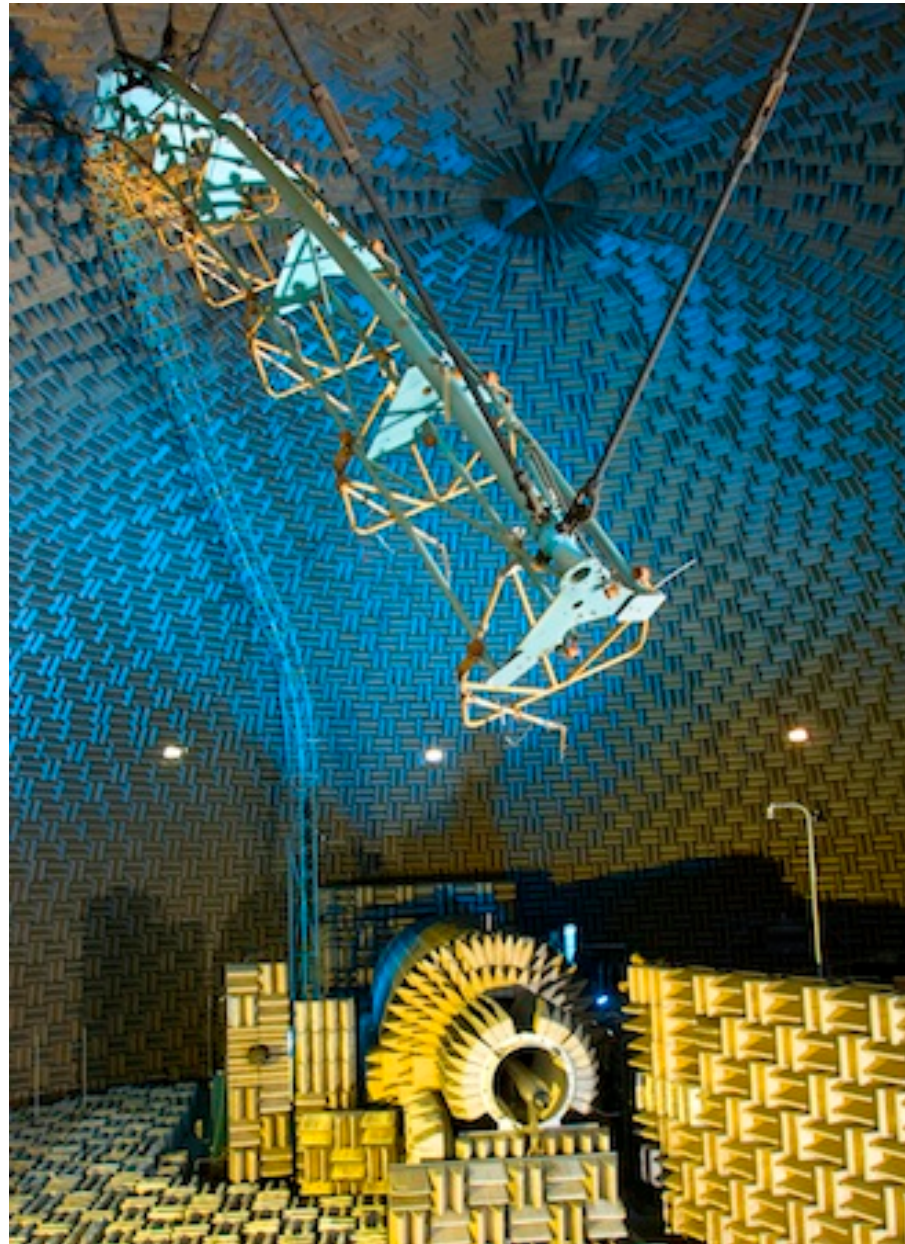


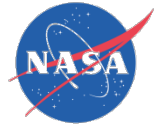
Chosen to provide best farfield acoustic arena.

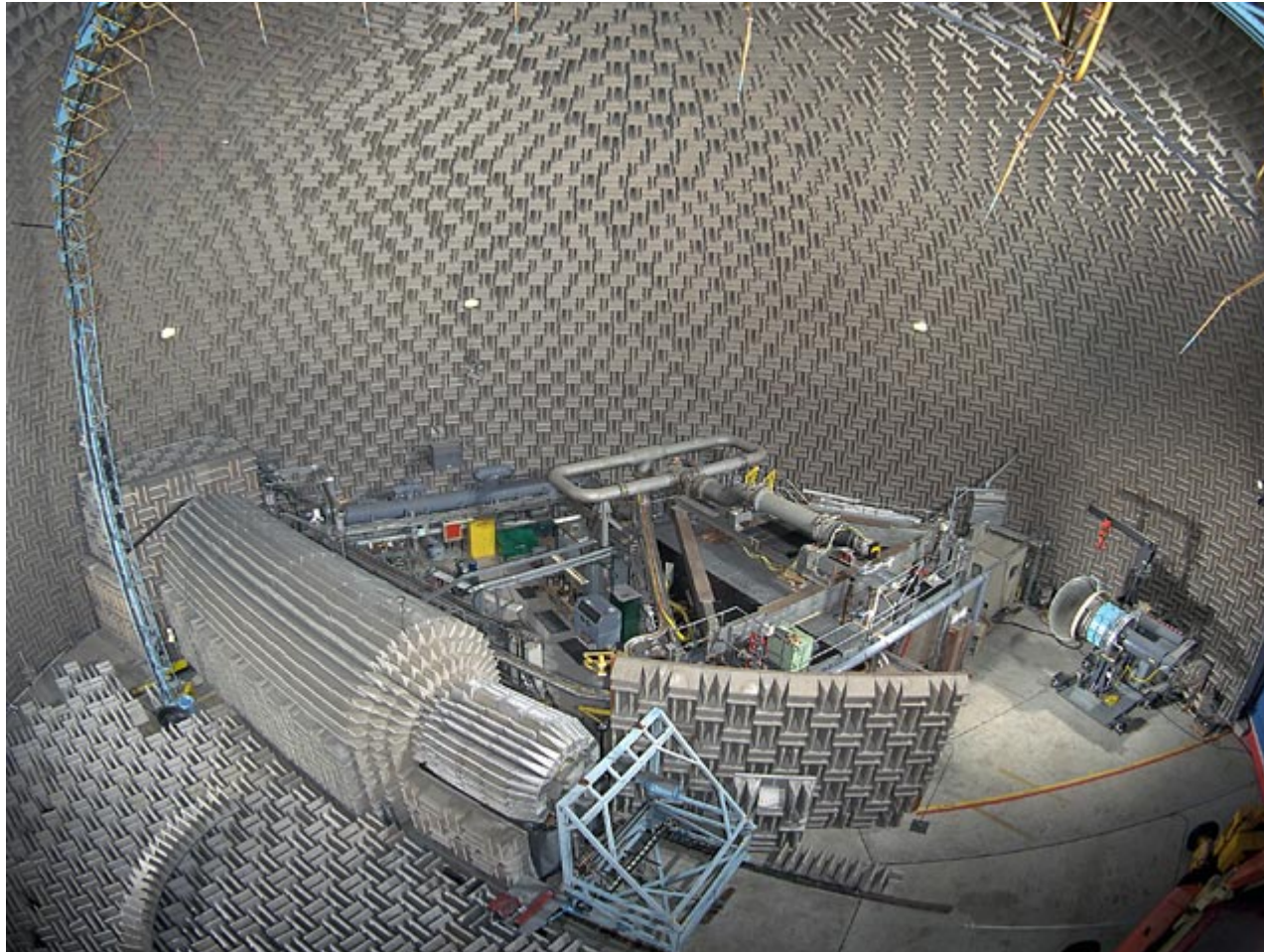
Location allows for addition of extensive sound barrier between motor & acoustic arena.

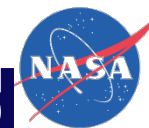
Minimizes interference with existing rigs. Will still be able to maintain ANCF I and share campaign crew.





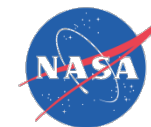






Concept / Power Ranges Considered

ID	RANGE/POWER	DESCRIPTION
Low	~ 5,000Ω/500HP	Low end facility power upgrade/ Belt/pulley transmission
Mid (1)	~ 6,000Ω/1,000HP	Low end facility power upgrade/ Gearbox coupling – right angle
Mid (2)	~ 10,000Ω/3,000HP	High end facility power upgrade/ Gearbox coupling – right angle / long shaft
T55	~ 16,000Ω/3500HP	Commercial turboshaft / long shaft
High (1)	~ 21,000Ω/7,000HP	High end facility power upgrade/ Gearbox coupling – straight / long shaft
High (2)	~ 21,000Ω/7,000HP	Hot Air turbine

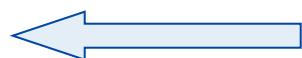


ANCF II 3-D Base Concept View

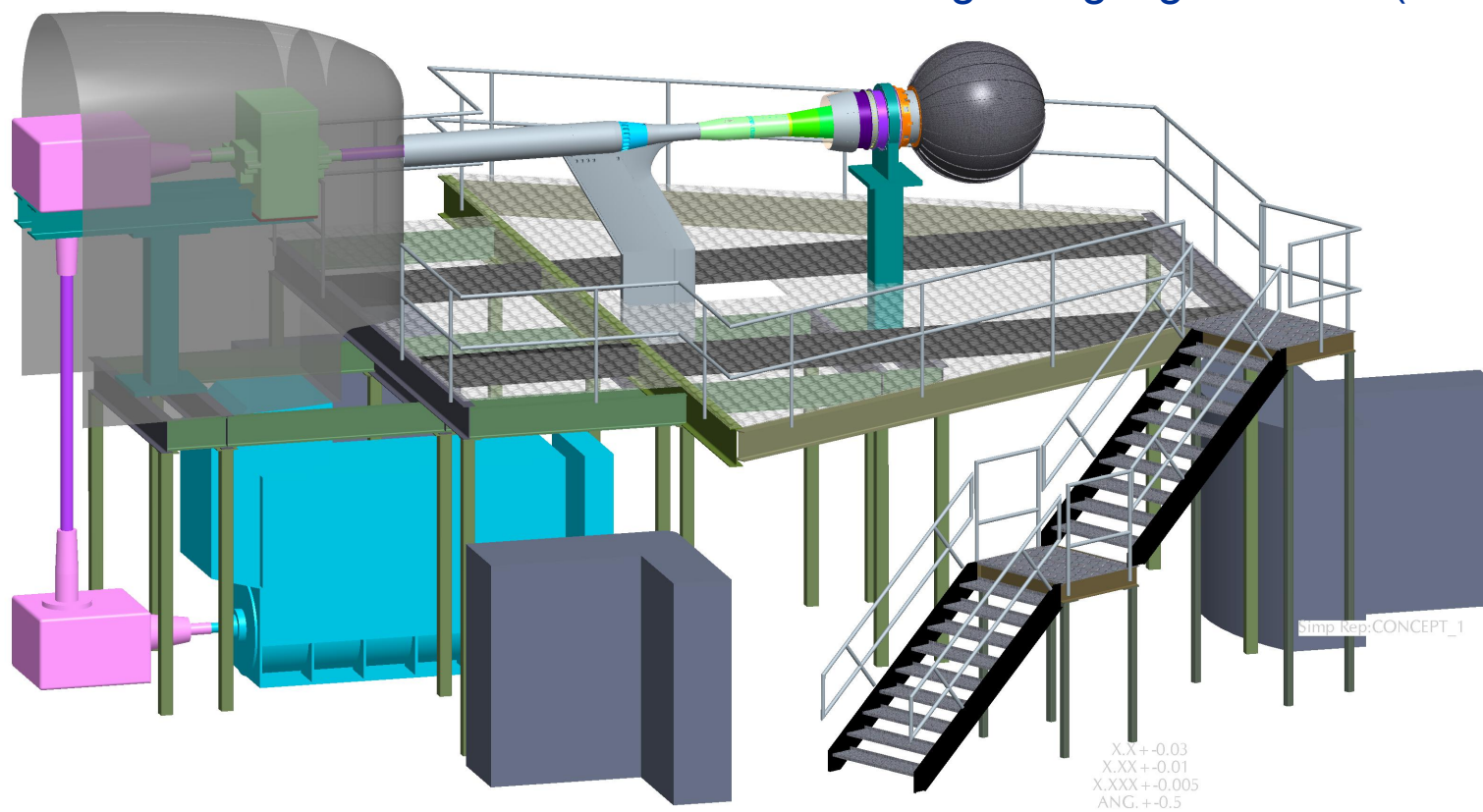
for 3000 HP

Initial 'conventional' layout

- very clean inlet arc
- motor inside
- flow obstructions in aft
- right angle gearboxes (\$/dB)



Main door for
exhaust flow



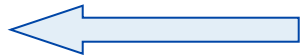


ANCF II Alternate Concept View

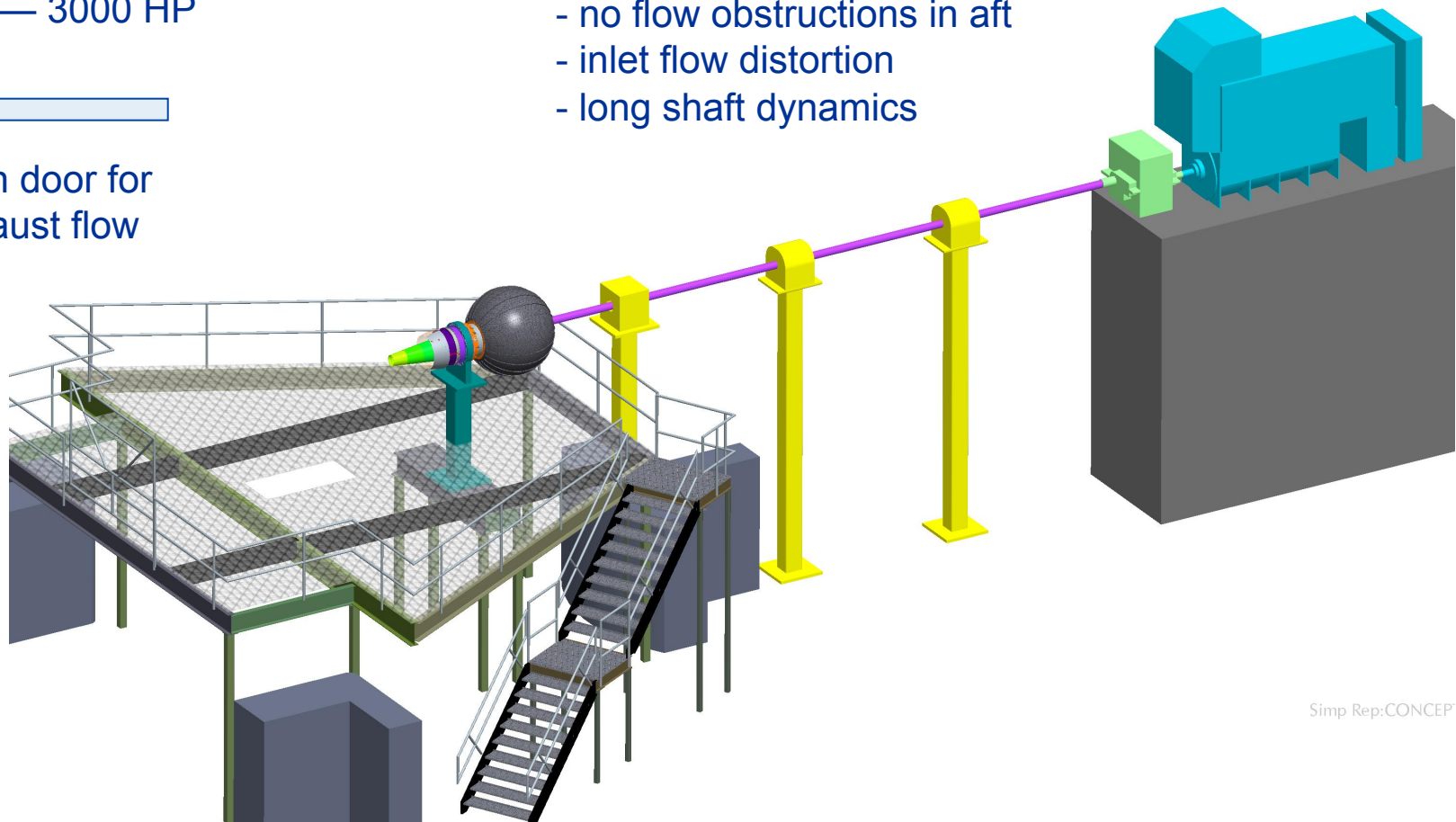
Alternate Inlet Driven

Originally for 7000 HP
— 3000 HP

- very clean aft arc / moderate fwd arc
- motor noise outside
- right angle gearboxes eliminated
- no flow obstructions in aft
- inlet flow distortion
- long shaft dynamics



Main door for
exhaust flow

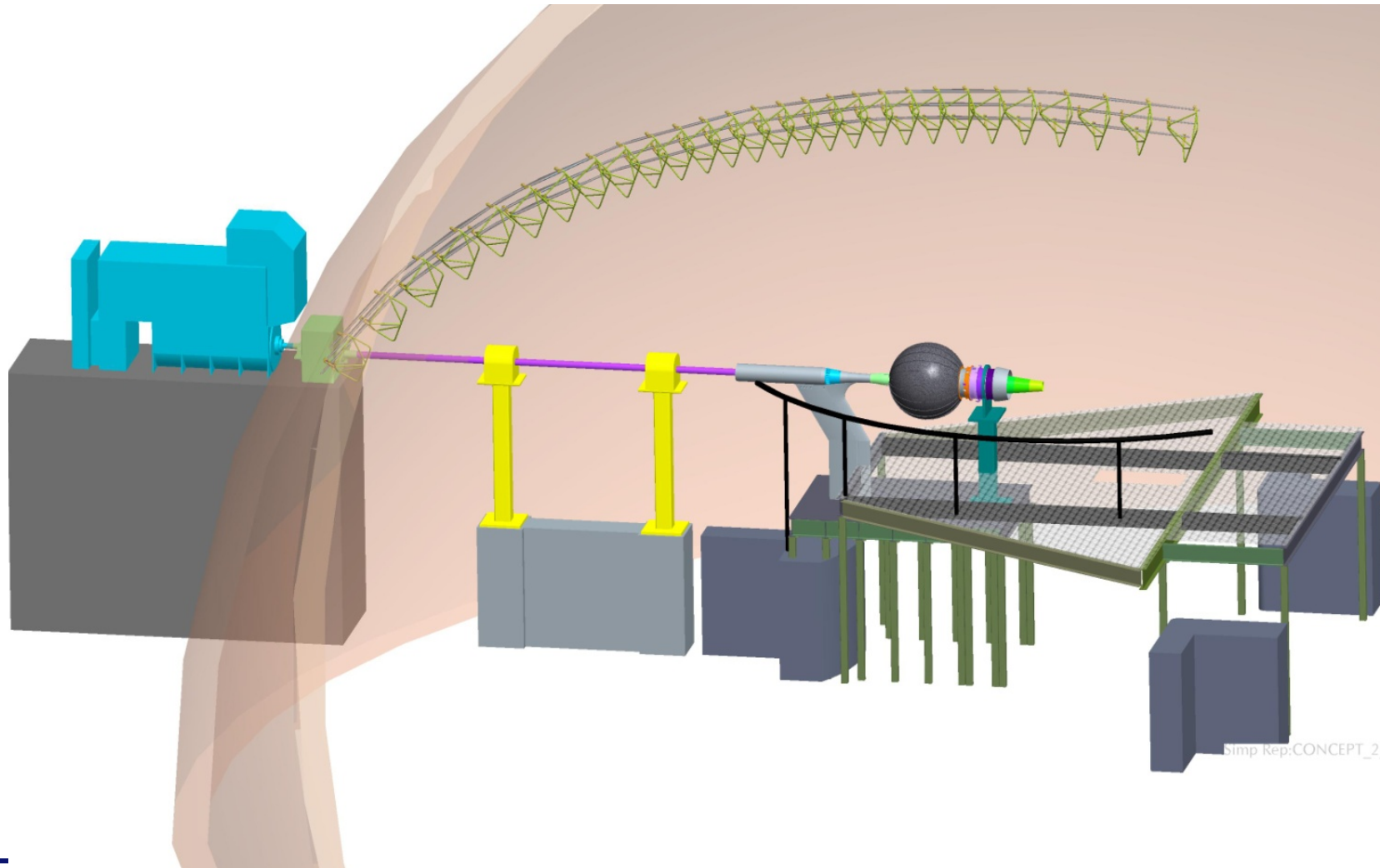


Simp Rep: CONCEPT



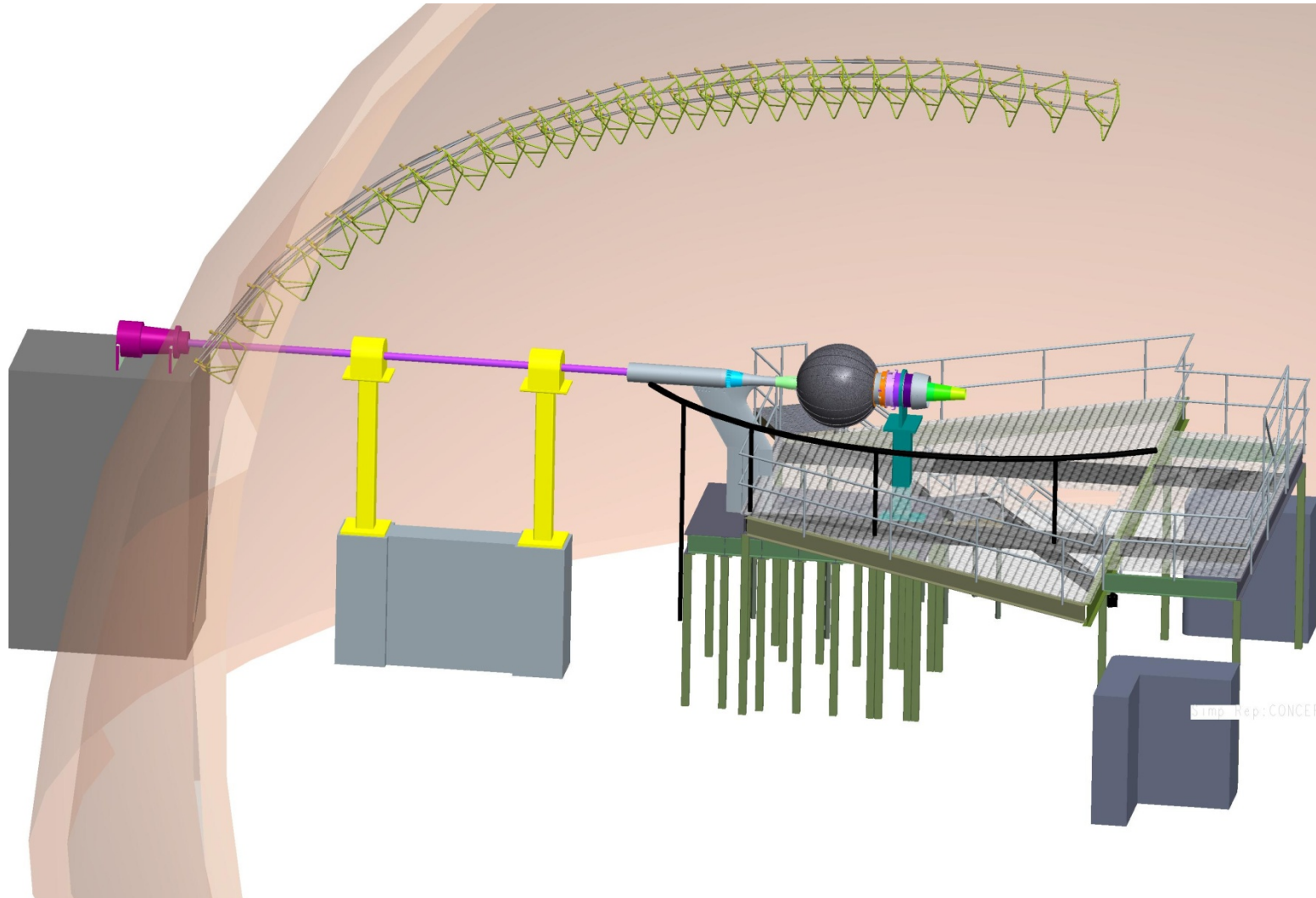
Electric Motor Drive Options alternate layout

Mid1 [Up to 6,000rpm / 1000hp] Mid2 [Up to 15,000rpm / 4000hp]



Honeywell T55 Turboshaft Drive

[16,000 rpm / 3500 hp]





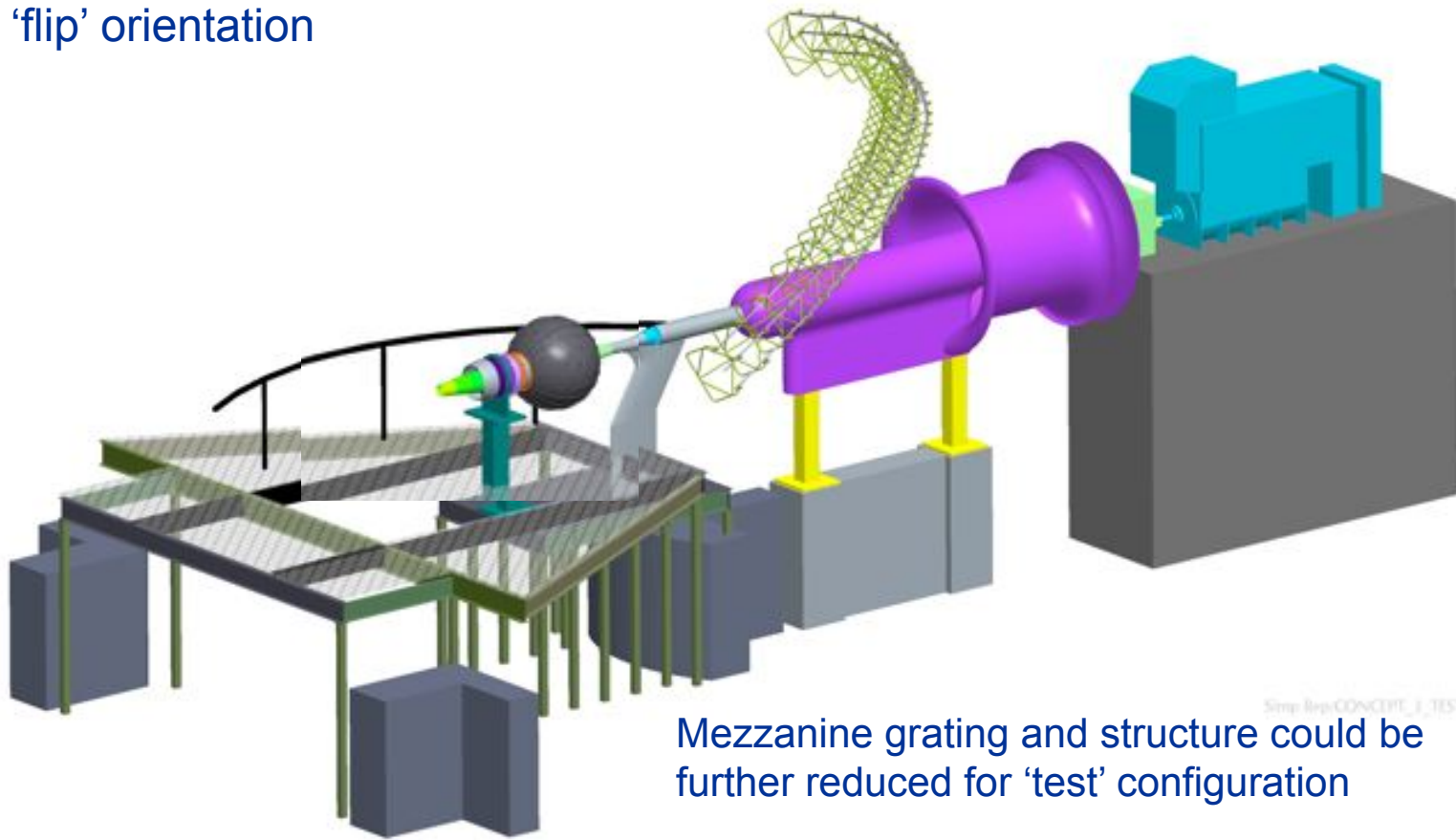
ANCF II FINAL CONFIGURATION

Current thinking:

- 3 -4000 HP +/- shaft driven
- External sited motor
- Ability to 'flip' orientation

Collector to exhaust

Can drive fan from aft – clean up inlet



Mezzanine grating and structure could be further reduced for 'test' configuration



Facility Upgrade Description



Power Upgrade for AAPL

Full Power Upgrade

- This power upgrade would be required for **mid (3000hp) and high (7000hp)** power range concepts
- The full power upgrade requires a dedicated 34.5 KV transformer and the associated cabling, breakers, etc
- This power upgrade would furnish the general electrical needs for AAPL
- Test scheduling limitation would be minimized
- Estimated cost for this full power upgrade is **\$1500K**



Power Upgrade: Generator

Generator Rental

- CATERPILLAR XQ2000
 - 2000 kW / 480 V / 60 Hz
 - Can rent on weekly or monthly basis (\approx \$10,000/week)
 - 1000 hp capability at \$10K/week and 3000 hp capability at \$19K week



Generator Purchase

- CATERPILLAR STAND-BY DIESEL
 - 2000 kW / 480V / 60 Hz
 - Purchase New = \$785,000
 - Purchase Used (2500 hrs. run time) = \$585,000
 - 1000 hp capability at \$600K and 3000 hp capability at \$1300K





Summary



Trade Study Updates

Previous cost slide represents complete development of ANCF2 and associated facility upgrades, and instrumentation – i.e. full

It was recognized that the estimated costs were probably not affordable in the current budget environment.

So the scope (costs) were revised to consider only what is needed to achieve a basic, but sufficient, IOC.

- eliminate right angle gearboxes (eliminates \$/noise/risk)
- use generator rental (eliminates facility power \$)
- inlet driven shaft capability (eliminates collector \$)
- defer overhead array (eliminates array \$)

Also looked at T55 alternative.



Concept Comparison (revised)

	T55 Turboshaft Drive	Electric motor w/ gearbox (Mid1 power)	Electric motor w/ gearbox (Mid2 power)	4 stage hot air turbine
Speed(rpm) / Power(hp)	16,000 / 3500	6000 / 1000	10,000 / 3000 or 15,000 / 4000	21,000 / 7000
Research Capability	All but highest PR takeoff (not reversible)	All PR approach ADP cutback (reversible)	All but highest PR takeoff (reversible)	All +margin (not reversible)
Technical Design Challenges	HI	MID	HI	LOW
Component Noise / Acoustic Environment	HI / MID	MID / MID	HI /MID	LOW / HI
Test Schedule Flexibility	HI	HI	HI	MID
Maintenance / Support	HI	LOW	MID	HI
Project Schedule	24 months	20 months	24 months	28 months
Cost(\$K)				
- Design	1500	1250	1500	1250
- Manufacturing	1250	1250	1250	1000
- Facility	400	100	100	500
- Procurement	850	400	900	1500
- Total	\$4000K	\$3000K	\$3750K	\$4250K

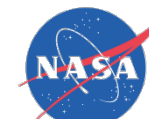


T55 Vs Electric Motor

- 1) Trade study assumes that both power sources will be mounted outside the Dome and require a similar drive train once inside the Dome to the fan**

- 2) Design requirement weight defines the importance of the design requirement- 1 (least important) to 5 (most important)**

- 3) Power concept score rates how well the concept satisfies the requirement- 1 (low) to 3 (high)**

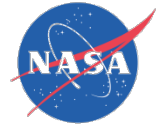


Requirements	Weight	T55 Turboshaft Drive	Score	Weighted Score	Electric Motor w/ Gearbox	Score	Weighted Score
Speed(rpm) / Power(hp)- ability to provide the full power at speed	4	16,000 / 3000- power limitations at certain speed ranges	2	8	10,000 / 3000 or 15,000 / 4000	3	12
Research Capability- satisfies range of speed/ power for fan operation, AND rotation directions	5	Limited speed control and unidirectional	1	5	Precise speed control and bidirectional	3	15
Technical Design Challenges- power source only; ease of integration of auxiliary systems	3	Multiple support systems- noise, emissions, cooling and containment. High level of effort	1	3	Commercial hardware with integrated support systems. Standard level of effort	2	6
Component Noise / Acoustic Environment- impact on acoustic test environment and outside environment	4	Very loud +130dB difficult to treat for outside and could allow noise into dome	1	4	Low noise design for motor is 85dB, but gearbox noise may be more	2	8
Test Schedule Flexibility- ease of test scheduling and making changes	3	Minimal logistics issues	3	9	Uncertainty with logistics of generators	2	6
Maintenance / Support- regular and rebuild maintenance and manpower for operation	3	High operation support required, regular and scheduled[return to vendor] maintenance	1	3	Low maintenance and manpower for operation	3	9
Project Schedule- design, procure, fab, install and checkout	2	More support systems required and increased checkout time of operations	1	2	Off shelf design with basic checkouts	2	4
Cost- design, procure, fab, install and checkout	5		2	10		2	10
TOTAL SCORE				44			70



Recommended Course of Action

1. Select a electrically driven motor ~ 3-4 KHP / 10-15 Krpm
2. Most “turn-key” option, and operationally simplest.
(Biggest risk is long shaft dynamics)
3. Utilize rental generators for power. Defer facility upgrade until operational tempo indicates need.
4. Inlet driven shaft – collector design and fabrication.
Exit acoustic data acquired
5. Capability to flip test rig and run drive shaft in reverse.
Inlet acoustic data acquired



Schedule and Cost Phasing

Breakdown Based on High Power Electric Motor

Schedule

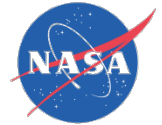
- Concept Study Kick-off 1/2010
- Concept Down-select 11/2010
- Project Go-Ahead 6/2011
- ANCF II Preliminary Design Review 4/2012
- ANCF II Critical Design Review 1/2013
- Hardware Delivery 10/2013
- Assembly and Checkout Complete 7/2014

Cost

	<u>Civil Servant</u>	<u>Contractor</u>	<u>Procurement</u>	<u>Total</u>
• FY11	\$ 225K	\$ 0K	\$ 25K	\$ 250K
• FY12	\$ 700K	\$ 325K	\$ 375K	\$1400K
• FY13	\$ 200K	\$1300K	\$ 600K	\$2100K
TOTAL	\$1125K	\$1625K	\$1000K	\$3750K

Assumes 75% engineering is CS, drafting is 50% CS, and manufacturing is all SSC

Summary



- 1) The new ANCF to match the flow and loading characteristics of the 9x15 Wind Tunnel scale models
 - 9x15 WT costs are **\$250K / week** power & labor.
 - ANCF II Operational costs would be **\$25- \$50K / week**.
- 2) Efficient operation at effective performance enables reimbursable work.
- 3) Evaluated designs directly transferable to the 9x15 greatly lowering the development risks.
- 4) Provide for in depth study of fundamental physics of fan broadband noise generation,
- 5) and the effects on performance, which will enable the development and validation of prediction codes.



Acknowledgement

Trade Study team included:

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